The effect of physical exertion on volunteers wearing self-contained breathing apparatus during a simulated rescue activity

Siyanda Ian Mthombeni

Department of Emergency Medical Care, University of Johannesburg
PO Box 524, Auckland Park, 2006, South Africa

s.mthombeni18@gmail.com

Andrew William Makkink

Lecturer: Department of Emergency Medical Care, University of Johannesburg
PO Box 524, Auckland Park, 2006, South Africa

amakkink@uj.ac.za

Christopher Owen Alexander Stein

Senior Lecturer: Department of Emergency Medical Care, University of Johannesburg
PO Box 524, Auckland Park, 2006, South Africa

cstein@uj.ac.za

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The effects of wearing a self-contained breathing apparatus (SCBA) during a simulated rescue activity were studied in 18 volunteers. Most existing studies have used treadmills to create exertion as opposed to actual simulated activity. Each participant completed a simulated rescue exercise whilst wearing the SCBA. After a minimum period of two weeks, the same participants completed an identical simulated rescue event, this time without the SCBA. Physiological variables that were assessed included heart rate, oxygen saturation (SpO_2), tympanic membrane temperature and blood lactate levels as well as time taken to complete the event and opinions of the use of the SCBA. There were no significant differences in the physiological variables measured between control and experimental groups. This is similar to some treadmill studies.

Keywords: Self-contained breathing apparatus; physiological effects; simulated rescue activity; personal protective equipment; tympanic temperature.

1 Introduction

Respiratory protective devices (RPDs) have a long history and can be traced as far back as Roman times. Pliny the Elder, a Roman writer, referred to how miners used loose-fitting animal bladders to protect themselves from toxic substances in the lead mines (United States Department of Labor Occupational Safety and Health Administration, 1999). The physiological effects of the various types of RPDs have been a source of interest for many researchers in an effort to predict how this may affect work ability and operational performance in a variety of contexts.

Medical rescue involves a diverse range of activities, some of which occur in adverse environments requiring respiratory protection (Mayne *et al*., 2009; Young, St Clair Gibson, Partington, Partington, & Wetherell, 2014). These kinds of rescue operations are typically physically demanding and often hazardous (Bennett, Hanley, Buckle, & Bridger, 2011). The risks of operating in such environments are reduced by wearing appropriate RPD, usually by way of self-contained breathing apparatus (SCBA). Apart from considerations of personal safety, rescuers often are required to provide emergency care and move patients to safety - both activities which can be affected by the constraints of protective equipment including SCBA, and which can influence patient outcome significantly.

Previous studies have identified a range of effects attributable to SCBA during work, most of which have involved exercise simulated on a treadmill. Some of these effects are increased heat strain (Bruce-Low, Cotterrell, & Jones, 2007; Petruzzello, Gapin, Snook, & Smith, 2009), extra mass added to rescuer's baseline mass (Hooper, Crawford, & Thomas, 2001; Williams-Bell, Boisseau, Mcgill, Kostiuk, & Hughson, 2009), decreased manoeuvrability (Louhevaara, Ilmarinen, Griefahn, Kunemund, & Makinen, 1995), increased breathing resistance (Hooper et al., 2001; Louhevaara *et al*., 1995), extra work of breathing (Butcher, Jones, Eves, & Petersen, 2006; Cheung, Petersen, & Mclellan, 2010) and increased external dead space due to the SCBA mask (Bruce-Low et al., 2007; Louhevaara *et al*., 1995).

Little descriptive data currently exists on the effects of SCBA on rescuers during exercise, particularly under realistic conditions. This study aimed to describe such effects by comparing four physiological variables at three time points during a simulated rescue exercise both with and without the use of SCBA.

2 Methods

2.1 Study Design

This study used a self-controlled, experimental design with four dependent variables (heart rate, arterial oxygen saturation, tympanic temperature and capillary lactate) and one factor, SCBA, with two levels (SCBA and no SCBA).

2.2 Sample

Study participants were drawn from a population of students in the Department of Emergency Medical Care at the University of Johannesburg. This population had all been taught, practiced and had passed an assessment on SCBA use during both fire and confined space search and rescue exercises. Students were approached by the researchers as a group and the study aims and methods were explained to them, along with possible risks and benefits. A printed information letter containing all details of the study was also distributed to the group. Those students who wished to participate in the study were required to sign a consent form. Exclusion criteria included any current or past history of illness precluding strenuous exercise or, in the case of females, pregnancy (female students participants were required to undergo a urine pregnancy test in order to rule this out prior to data collection).

2.3 Data Collection Procedures

Data arising from the experimental (with SCBA) and control (without SCBA) groups were collected on two different days, a minimum of two weeks apart. Participants were requested to refrain from smoking and from consuming caffeine and alcohol from 24 hours prior to the beginning of data collection. Before the first day of data collection participant's height and eight were measured using a mechanical column scale with height rod (Seca, Seca 700. Birmingham, UK).

2.3.1 Simulated Rescue Incident

A rescue incident was simulated which involved accessing, packaging and removing a patient from an adverse environment requiring SCBA use. The incident was set up in a building on one campus of the University of Johannesburg. The building had a combination of stairs and ramps between each floor, between the ground and seventh floors.

Participants were required to ascend from the ground to the seventh floor in pairs using a combination of stairs and ramps, carrying spinal immobilisation equipment (a spine board, harness and head immobilisation blocks) in a basket stretcher (Ferno-Washington Inc. Wilmington, OH, USA). The patient rescue equipment to be carried had a combined weight of 19kg. Participant pairs were required to traverse three vertical barriers on the second, fourth and six floors. The barriers comprised a standard gum tree pole placed at a height of 94 cm above the floor level and covered the entire width of the access route (minimum 367 cm). Each pole was secured on both ends with utility rope to ensure that participants were able to climb over it without any risk of dislodgement.

Once on the seventh floor of the building, each pair of participants were required to fully immobilise a simulated patient (CMC Rescue, I.A.F.F. Rescue Randy 1475, Santa Barbara. USA) weighing approximately 75kg using the immobilization devices that had been carried with them. The immobilised patient was then placed and secured in the basket stretcher and carried back to the starting point on the ground floor of the building by following the reverse of the original route, including the vertical obstacles. Combined weight of the immobilisation equipment and simulated patient was approximately 94kg.

Physiological variables were measured at the start of the exercise with participants at rest, after donning the SCBA equipment (designated measurement point PRE). Further measurements were taken when participants arrived at the simulated patient's side on the seventh floor (measurement point PT) and upon returning to the starting point on the ground floor, prior to doffing of the SCBA equipment (measurement point POST).

2.3.2 *Equipment and Instrumentation*

Participants wore regular uniform comprising a regulation cotton overall (Supplycor, Johannesburg, South Africa), regulation boots and relevant underclothing as they would normally wear. The SCBA was comprised of a Panorama Nova Facemask attached to a lung demand valve and using a 6 litre 300 bar cylinder attached to a backplate (Drägerwerk, Lübeck, Germany). This was the same SCBA equipment that participants had been trained and assessed with previously and had a total weight of approximately 10.4kg.

Heart rate was measured using either a Suunto T3c heart rate monitor (Suunto, Suunto Oy, Vantaa, Finland) or a Polar RS200 heart rate monitor (Polar Electro, Kempele, Finland). Non-invasive arterial blood oxygen saturation levels were measured with a Biolight portable pulse oximeter (Biolight Medtech Co. Ltd, m700, Guangdong, China). The same finger was used for initial and subsequent measurements.

Blood lactate was measured using a portable 1710 Lactate ProTM analyser (Arkray Factory Inc, KDK Corporation, Shinga, Japan) that was calibrated before the start of each activity in accordance with manufacturer specifications. Capillary blood from the index finger was sourced using a commercially available lancet device (Accu-chek Softclix Pro Lancets, Indianapolis, IN, USA). Tympanic membrane temperature was measured using a specialist tympanic thermometer (Braun Thermoscan, IRT 3020, Braun AG, Kronburg, Germany).

2.4 Ethical Considerations

Ethical approval for this study was obtained from the Faculty of Health Sciences Research Ethics Committee at the University of Johannesburg. All participants were informed of the study aims, methods and associated risks and benefits verbally and in writing, and were required to sign a consent form prior to their involvement in the study. Participants were informed that they were allowed to withdraw their consent at any stage during the study without any consequences.

2.5 Statistical analysis

Multivariate repeated measures analysis of variance was used to compare heart rate, SpO_2, tympanic temperature and capillary lactate between control and SCBA groups (*group* factor), and within each group over the three measurement points (*stage* factor, referring to the three stages with data measurement occurring in each one). Pairwise comparisons between measurement points for each physiological variable used the Bonferroni adjustment for multiple comparisons. $P < 0.05$ was considered significant and SPSS (IBM SPSS, version 22.0, IBM Corporation, New York, USA) was used for statistical analysis.

3 Results

3.1 Participants

Participant descriptive data are shown in Table 1. Six participants (33%, five male and one female) had BMI values greater than or equal to the upper limit of the range considered as normal or healthy weight.

Table 1. Participants

	Male (n = 15)		Female (n = 3)	
	Mean	**95% CI**	**Mean**	**95% CI**
Age (years)	24.1	22.3;25.9	23.8	20.4;27.2
Weight (kg)	76.2	68.7;83.2	62.9	53.3;72.6
Height (m)	1.8	1.7;1.8	1.7	1.6;1.8
BMI (kg)/(m^2)	24.5	22.9;26.2	22.6	19.8;25.3

BMI = Body Mass Index

3.2 Descriptive Data

Descriptive data for the control and SCBA groups at each measurement point are shown in Table 2 and Table 3.

Table 2. Descriptive Data Over Measurement Points: Control Group

	Control (n = 18)					
	PRE		PT		POST	
	Mean	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
Heart rate (beats/min)	86.8	79.7;94.0	117.1	107.0;127.1	164.0	156.0;175.7
SpO_2 (%)	96.4	95.7;97.1	94.3	90.1;99.0	95.7	95.0;96.4
T-tym (°C)	36.4	36.3;36.6	36.3	36.1;36.6	36.4	36.1;36.6
Lactate (mmol/l)	2.7	1.7;3.6	2.9	2.1;3.8	6.4	4.4;8.4

SpO_2 = arterial oxygen saturation; T-tym = tympanic membrane temperature

Control group means for heart rate and lactate increased over the three stages while tympanic temperature means showed very little change. Mean SpO_2 declined slightly at the PT stage, but recovered by the POST stage (Table 2). SCBA group mean changes in these variables were very similar to those in the control group. Only the PT stage mean heart rate showed a reasonably large difference (24.9 beats/min) between control and SCBA groups (Table 3).

Table 3. Descriptive Data Over Measurement Points: SCBA Group

	SCBA (n = 18)					
	PRE		PT		POST	
	Mean	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
Heart rate (beats/min)	81.3	75.0;87.5	142.0	130.3;153.7	166.2	156.7;175.7
SpO_2 (%)	96.2	95.4;97.0	95.3	94.3;96.4	94.8	93.8;95.9
T-tym (°C)	36.5	36.3;36.7	36.3	36.1;36.6	36.3	36.0;36.6
Lactate (mmol/l)	2.7	1.8;3.6	3.3	2.3;4.2	6.4	4.4;8.4

SpO_2 = arterial oxygen saturation; T-tym = tympanic membrane temperature

3.3 Between Groups Effects

Multivariate analysis indicated that that the factor *group* (SCBA vs. control) did not have a significant effect on the dependent variables ($p = 0.392$), while the factor *stage* (p < 0.01) and the interaction of *group* and *stage* (p = 0.022) did. SCBA vs. control differences for each dependent variable are shown in Table 4.

Table 4. Control vs SCBA Differences

	Difference (Control vs SCBA)	95% CI	P
Heart rate (beats/min)	-7.2	-15.8;1.3	0.096
SpO_2 (%)	0.1	-1.6;1.6	0.963
T-tym (°C)	0.1	-0.2;0.3	0.926
Lactate (mmol/l)	-0.2	-1.6;1.1	0.717

SpO_2 = arterial oxygen saturation; T-tym = tympanic membrane temperature

3.4 Within Groups Effects

Pairwise comparisons of mean differences for each physiological variable over both control and SCBA groups identify only five significant pairwise differences in two variables. All stage differences in the first variable, heart rate, were significant while only the PRE vs. POST and PT vs. PRE differences were significant for the second, lactate.

Table 5. Physiological Variables: All Pairwise Comparisons

	Pair	Difference	95% CI	P
Heart rate (beats/min)	PRE vs PT	-45.5	-54.0;-37.1	< 0.001
	PT vs POST	-35.6	-46.0;-25.1	< 0.001
	PRE vs POST	-81.1	-90.6;-71.5	< 0.001
SpO_2 (%)	PRE vs PT	1.4	-1.2;4.1	0.542
	PT vs POST	-0.4	-3.0;2.1	1
	PRE vs POST	1.0	0.1;1.9	0.018
T-tym (°C)	PRE vs PT	0.1	-0.6;0.3	0.358
	PT vs POST	-0.1	-0.2;0.2	1
	PRE vs POST	0.1	-0.2;0.4	0.869
Lactate (mmol/l)	PRE vs PT	-0.4	-1.4;0.6	0.949
	PT vs POST	-3.5	-5.0;-2.0	< 0.001
	PRE vs POST	-3.9	-5.4;-2.4	< 0.001

PRE = prior to exertion, at rest; PT = on arrival at simulated patient's side; POST = immediately after exertion, at rest; SpO_2 = arterial oxygen saturation; T-tym = tympanic membrane temperature.

4 Discussion

This study sought to determine the effect that SCBA use had on certain physiological variables. The study generated findings that may be useful to persons involved in the use of SCBA.

The significant increase in heart rate observed within groups is consistent with other findings and can be attributed to the physiological strain and demands of the exercise (Eglin, 2007; Eglin, Coles, & Tipton, 2004; Young et al., 2014). The sustained increase in heart rate during the patient carrying phase in both groups indicates the extra exertion required to bear the load. Observed heart rates were lower than in some treadmill studies (Bakri, Lee, Nakao, Wakabayashi, & Tochihara, 2012; Dreger, Jones, & Petersen, 2006; Ftaiti, Duflot, Nicol, & Grélot, 2001; Taylor, Lewis, Notley, & Peoples, 2011) and higher than in others (Young et al., 2014). The fitness of participants and varying intensity of exertion may account for this. These variations may be attributed to the effect of the lack of jackets as observed by Ftaiti *et al*. that resulted in a significant decrease in corresponding heart rate (Ftaiti *et al*., 2001). Another factor possibly affecting a lack of heart rate difference between groups is the parasympathetic stimulating effect of expiration through a SCBA regulator, which has been suggested by Schipke & Pelzer (2001). The lack of significant difference between groups, although largely unexpected, is one that has been observed in other studies (Eves, Jones, & Petersen, 2005; Nelson, Haykowsky, Mayne, Jones, & Petersen, 2009)

The observed decrease in SpO_2 at peak activity was in line with the results of similar treadmill studies (Eves *et al*., 2005), although the increase in SpO_2 levels in the control group was unexpected. This rise in SpO_2 levels during exercise has been observed before in a similar study (Makkink, 2010). Although significant changes in SpO_2 levels were noted within groups, there was no significant difference observed between groups.

The increases in blood lactate levels in both control and experimental groups during the simulated rescue activity were an indicator of the intensity of activity. It is interesting to note that in both groups, although blood lactate levels increased from the start to patient access, there was also a marked increase in this effect during the retrieval phase. This was an indication of the increased work intensity associated with patient carrying (Barnekow-Bergkvist, Aasa, Angquist, & Johansson, 2004; Bugajska, Zużewicz, Szmauz-dybko, & Konarska, 2007). The levels observed were similar to other studies (Eves, Petersen, & Jones, 2002) but were lower than some high-intensity studies (Mamen, Oseland, & Medbø, 2013). There was no significant difference between groups, a finding similar to that of Mamen et al. who compared physiological responses between two different activities associated with firefighting (Mamen *et al*., 2013).

The decrease in tympanic membrane temperature was unexpected as increased physical activity was anticipated to result in a corresponding temperature increase (Carter, 1999). The reasons for this decline in temperature include, but not limited to, the nature of the clothing worn and its lack of thermal retention properties; or the fall in temperature may be the result of the evaporation of sweat from the clothing. Some other theories that were postulated by the researchers may be related to the decreasing temperature of air delivered into the face piece of the SCBA as a result of cylinder emptying. No studies could be found that measured this phenomenon.

5 Conclusion

Overall, this study demonstrated that the activity associated with patient retrieval resulted in a significant increase in physical activity and resultant changes in physiological variables. No significant differences were observed in physiological variables between the groups with and without SCBA. Although this was not expected, the results are similar to some other studies. A novel finding was the slight increase in SpO_2 in the SCBA group.

Heart rates observed in this study were generally lower than those recorded in treadmill studies. Many treadmill activities, especially those using exhaustion protocols, do not adequately reflect the dynamic nature of the rescue environment and may by their nature, be overestimating exertion levels that would be encountered in the actual or simulated rescue environments. More research is required using simulated or real-life rescue activities to determine their actual exertional demands. Comparative workload analysis between actual or simulated rescue activities and treadmill exercises will assist in determining more relevant exertional parameters.

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